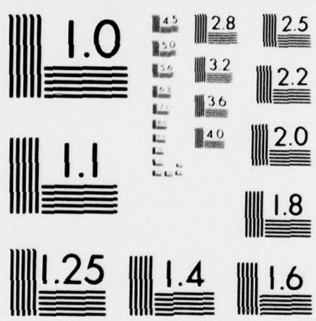
AD-A062 171 PENNSYLVANIA STATE UNIV UNIVERSITY PARK APPLIED RESE--ETC F/G 20/4
ACOUSTIC EFFICIENCY OF BOUNDARY-LAYER TRANSITION.(U)
NOV 78 G C LAUNCHLE N00017-73-C-1418
UNCLASSIFIED TM-78-285 NL

| OF |
AD
A062171

END
DATE
FILMED
3-79
DDC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(6) ACOUSTIC EFFICIENCY OF BOUNDARY-LAYER TRANSITION.

(10) G. C./Lauchle

(11) 7 Nov 78

(12) 16p.

(9) Technical ~~Memorandum~~,
File No. TM 78-285
November 7, 1978
Contract No. N00017-73-C-1418 (15)

Copy No. 48

(14) TM-78-285

The Pennsylvania State University
APPLIED RESEARCH LABORATORY
Post Office Box 30
State College, PA 16801

NAVY DEPARTMENT

NAVAL SEA SYSTEMS COMMAND

Approved for Public Release
Distribution Unlimited

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TM 78-285	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ACOUSTIC EFFICIENCY OF BOUNDARY-LAYER TRANSITION		5. TYPE OF REPORT & PERIOD COVERED Technical Memorandum
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) G. C. Lauchle		8. CONTRACT OR GRANT NUMBER(s) N00017-73-C-1418
9. PERFORMING ORGANIZATION NAME AND ADDRESS Applied Research Laboratory P. O. Box 30 State College, PA 16801		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Sea Systems Command Washington, DC 20362		12. REPORT DATE November 7, 1978
		13. NUMBER OF PAGES 9
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release. Distribution Unlimited
Per NAVSEA - Nov. 27, 1978.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

boundary layer
transition
radiated noise
flow noise

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The radiated noise due to incompressible boundary-layer transition on an infinite, rigid planar surface has been recently analyzed (ARL TM 78-204, 28 July 1978). The results of that analysis are the power spectrum and directivity of the farfield sound pressure due to a unit span of transition zone flow. In this note, we further analyze transition zone flow noise by deriving an expression for the acoustic efficiency. We compare this efficiency with the acoustic efficiency of a fully-developed turbulent boundary

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. layer and find that the radiation from the transition zone is considerably more efficient. In particular, for typical values of the Reynolds numbers upon which this comparison depends, transition zone radiation is approximately a thousand times more efficient.

Subject: Acoustic Efficiency of Boundary-Layer Transition

References: See page 9

Abstract: The radiated noise due to incompressible boundary-layer transition on an infinite, rigid planar surface has been recently analyzed (ARL TM 78-204, 28 July 1978). The results of that analysis are the power spectrum and directivity of the far-field sound pressure due to a unit span of transition zone flow. In this note, we further analyze transition zone flow noise by deriving an expression for the acoustic efficiency. We compare this efficiency with the acoustic efficiency of a fully-developed turbulent boundary layer and find that the radiation from the transition zone is considerably more efficient. In particular, for typical values of the Reynolds numbers upon which this comparison depends, transition zone radiation is approximately a thousand times more efficient.

Acknowledgment: The support of the U.S. Naval Sea Systems Command, Code 0351, is greatly appreciated.

November 7, 1978
GCL:cac

TABLE OF CONTENTS

I. INTRODUCTION

Recently, the author [1] analyzed the noise radiated by boundary-layer transition. An expression for the power spectrum and directivity of the radiated pressure was developed in this analysis. In his examples, it was shown that the predicted spectra agree quite well with available experimental spectral data. It was further discussed that the radiated energy due to fully-developed turbulent motion over the test bodies also contribute significantly to the observed spectra, particularly at higher frequencies. Because of this observation we are motivated to compare the relative efficiencies of the two types of hydrodynamic sources. This comparison is developed in this note.

II. ANALYSIS

In general, the acoustic efficiency is defined by:

$$\eta = N_a/N_h \quad , \tag{1}$$

where N_a is the acoustic power radiated to the farfield by the source under consideration, and N_h is the work expended per unit time by the hydrodynamic motions within the acoustic source region. We will first examine the acoustic efficiency for the transition zone.

A. Transition Zone Acoustic Efficiency

We begin with the power spectrum of the acoustic pressure radiated per unit spanwise width of boundary-layer transition [1]:

$$\frac{\partial G}{\partial x_3} = \frac{\cos^2\theta \; \sigma^2(x_o) \; u_c \; (\Delta x)^2}{2\pi^2 r^2 c^2} (\kappa\Delta x)^2 F(\kappa\Delta x, \; u_o/u_c) \; [1+(\omega t_i)^2]^{-1} \quad , \tag{2}$$

where θ is the angle between the flow direction and observation point, which is a distance r away from the initial line of laminar flow breakdown, x_o. The small distance, Δx, is the streamwise extent of intermittent transitional flow, u_c is the velocity of burst convection, c is the velocity of sound, ω is the radian frequency, with

$$\kappa = \omega/u_o \quad , \tag{3}$$

where u_o is the free-stream velocity. The stress

$$\sigma(x_1) = \tau_T \, (x_1) - \tau_L \, (x_1) \tag{4}$$

represents the difference between the turbulent mean value of wall shear stress at position x_1 and a corresponding laminar value at the same point. The time, t_i, is representative of the time required for the wall shear stress to change from a locally laminar (or turbulent) to a locally turbulent (or laminar) value as turbulent bursts are created or convected by a given location on our rigid planar surface. The frequency function, $(\kappa\Delta x)^2F(\kappa\Delta x, u_o/u_c)$ is presented graphically in Figure 7 of Reference [1]. Typically, it is only weakly dependent on

u_o/u_c, rises at 12dB/octave for $(\kappa\Delta x)<1.0$ and approaches a constant ($\simeq$ 28 for $u_c/u_o = 0.7$) for $(\kappa\Delta x) > 1.0$.

If we express equation (2) as:

$$\frac{\partial G}{\partial x_3} = \cos^2\theta \, \langle p_o^{\,2} \,(\omega,\, u_o/u_c)\rangle \quad ,$$

the total acoustic power generated per unit spanwise width of transition is obtained by integrating the intensity over all frequencies and over the surface of a large sphere of radius r, i.e.,

$$N_a = \int_0^\infty \frac{\langle p_o^{\,2}\rangle}{\rho c}\, d\omega \int_0^{2\pi}\int_0^{\pi} r^2\cos^2\theta\sin\theta d\theta d\phi = \frac{4\pi r^2}{3\rho c}\int_0^\infty \langle p_o^{\,2}\rangle d\omega \qquad (5)$$

$$N_a = \frac{2\sigma^2(x_o)\; u_c\; (\Delta x)^2}{3\pi\rho c^3}\int_0^\infty (\kappa\Delta x)^2 F(\kappa\Delta x,\, u_o/u_c)[1+(\omega t_i)^2]^{-1} d\omega . \qquad (6)$$

For $u_c/u_o = 0.7$, we can approximate the integrand by a constant (28 for this case) and integrate between the half-power points. In particular,

$$N_a \simeq \frac{2\sigma^2(x_o)\; u_c\; (\Delta x)^2}{3\pi\rho c^3}\left(28\frac{u_c}{\Delta x}\right)\int_{0.5}^{\Delta x/u_o t_i} d(\kappa\Delta x)$$

$$\simeq 19.6\left[\frac{2\sigma^2(x_o)\; u_o^{\,2}\; \Delta x}{3\pi\rho c^3}\right]\left[\frac{\Delta x}{u_o t_i} - 0.5\right] \quad .$$

Because t_i is very much smaller than $\Delta x/u_o$, we obtain:

$$N_a \simeq \frac{4\sigma^2(x_o)\; u_o\; (\Delta x)^2}{\rho c^3 t_i} \qquad (7)$$

for the total acoustic power generated by boundary-layer transition of unit spanwise width.

The hydrodynamic power generated within a unit spanwise width of boundary-layer transition is given by:

$$N_h = u_o \int_{x_o}^{x_o+\Delta x} \tau_o \, dx_1 \quad , \qquad (8)$$

where τ_o is the mean value of the wall shear stress. Because bursting flow occurs between the limits of integration, we would expect that

$$\tau_o\,(x_1) = \tau_T\,(x_1)\gamma(x_1) + [1-\gamma(x_1)]\;\tau_L\,(x_1) \quad ,$$

where $\gamma(x_1)$ is the intermittency factor. Because

$$\tau_o = (\tau_T - \tau_L)\;\gamma + \tau_L \quad ,$$

where $(\tau_T - \tau_L) = \sigma \simeq 0.9\tau_T$ [1], we let

$$\tau_o\ (x_1) \simeq \gamma(x_1)\ \sigma\ (x_1) \quad . \tag{10}$$

The intermittency distribution can be calculated using [2]:

$$\gamma(\overline{x}) = 1\text{-}\exp(-4.185\ \overline{x}^2) \quad , \tag{11}$$

where

$$\overline{x} = \frac{x_1 - x_o}{\Delta x} \quad . \tag{12}$$

We again assume, as in the original noise analysis [1], that;

$$\sigma(x_o) \simeq \sigma(x_o + \Delta x) \tag{13}$$

such that

$$N_h \simeq u_o\ \sigma(x_o) \int_{x_o}^{x_o + \Delta x} \gamma(x_1)\ dx_1 \quad .$$

Making the appropriate change of integration variable, we find that

$$N_h \simeq u_o\ \Delta x\ \sigma(x_o) \left[1 - \int_0^1 \exp(-4.185\ \overline{x}^2)\ d\overline{x}\right] \quad . \tag{14}$$

We now let $t^2 = 4.185\overline{x}^2$, $d\overline{x} = 0.488\ dt$, and find:

$$N_h \simeq u_o\ \Delta x\ \sigma(x_o)\ [1 - 0.488\ \frac{\sqrt{\pi}}{2}\ \mathrm{erf}(2.046)]$$

$$N_h \simeq 0.572\ u_o\ \Delta x\ \sigma(x_o) \quad . \tag{15}$$

We can now divide equation (7) by equation (15) to get:

$$\eta_{tr.} \simeq \frac{7\ \sigma(x_o)\ \Delta x}{\rho c^3 t_i} \quad . \tag{16}$$

It will prove expedient to re-work equation (16) a little further. We expect that t_i scales with the turbulent velocities very near and normal to the surface; these velocities scale with the friction velocity, u_*. We might further expect that there is a critical height, y_c, which is comparable to the viscous sub-layer thickness such that:

$$t_i \simeq y_c/u_* \quad . \tag{17}$$

By definition,

$$y_c^+ = u_*\ y_c/\nu \quad , \tag{18}$$

where ν is the kinematic viscosity; thus,

$$t_i \simeq y_c^+ \frac{\nu}{u_*^2} \quad , \qquad (19)$$

and,

$$\eta_{tr.} \simeq \frac{7\sigma(x_o)\ \Delta x\ u_*^2}{\rho c^3\ y_c^+\ \nu} \quad . \qquad (20)$$

Now σ is very nearly equal to τ_T, so we let [3]

$$\sigma(x_o) \simeq 0.0288\ \rho u_o{}^2\ Re_{x_o}{}^{-1/5} \quad , \qquad (21)$$

and also let $u_* \simeq u_o/30$ to get

$$\eta_{tr.} \simeq 2.24 \times 10^{-4}\ \frac{Re_{\Delta x}\ M^3}{Re_{x_o}{}^{1/5}\ y_c^+} \quad . \qquad (22)$$

In equation (22), Re_{x_o} is the transition Reynolds number and $Re_{\Delta x}$ is the transition streamwise extent Reynolds number which is approximately related to Re_{x_o} by [4]:

$$Re_{\Delta x} \simeq 60 Re_{x_o}{}^{2/3} \quad . \qquad (23)$$

A specific value cannot be assigned to y_c^+ at this time. A series of controlled experiments appear to be required in order to find the dependence of t_i on $u_o{}^2/\nu$ from which y_c^+ may be deduced. For order of magnitude estimates, however, we know that y_c^+ must be small ($5 < y_c^+ < 30$), viz., Tennekes and Lumley [5]. We see from equation (22) that the radiation efficiency of the laminar-to-turbulent transition zone depends upon the cube of the free-stream Mach number; a result to be expected for dipole sources.

For comparative purposes we would like to compare this efficiency with that of a fully-developed turbulent boundary layer flow. We must first obtain an expression for the efficiency of the latter.

B. Fully-Developed Turbulent Boundary Layer Acoustic Efficiency

Both Tam [6] and Landahl [7] recently developed theoretical models for the sound power generated by fully-developed boundary layer turbulence. Landahl derived the following proportionality for the efficiency:

$$\eta_{TBL} \sim \frac{u_*}{u_o}\ M_*{}^3 \quad ,$$

where $M_* = u_*/c$. Because the constant of proportionality is not implied in this relation, we cannot use it in a quantitative comparison with equation (22).

On the other hand, Tam did not derive an explicit expression for the efficiency, but did give an expression for the acoustic power generated per unit surface area of boundary layer turbulence. In particular,

$$N_{TBL} = \frac{4\pi\tau_T^2}{\rho c} \int_0^\infty F(S, M)\, dS \qquad , \qquad (24)$$

where the integral is presented graphically in Reference [6] as a function of Mach number, M. Tam concluded that the magnitude of this integral increases rather rapidly with Mach number (slightly faster than M^2). We have thus been able to approximate it by:

$$\int_0^\infty F(S, M)\, ds \simeq 0.015M^2 \ (M > 0) \qquad . \qquad (25)$$

The hydrodynamic power generated per unit surface area of boundary layer turbulence is given by:

$$N_{h_T} = u_o \tau_T \qquad , \qquad (26)$$

so we would expect that:

$$\eta_{TBL} \simeq \frac{0.188\ \tau_T\ M^2}{\rho c u_o} \qquad (27)$$

Using equation (21) for τ_T, equation (27) reduces to:

$$\eta_{TBL} \simeq 5.43 \times 10^{-3}\ Re_{x_1}^{-1/5}\ M^3 \qquad . \qquad (28)$$

We compare the transition zone acoustic efficiency with that of the fully-developed turbulent boundary layer flow by dividing equation (22) by equation (28), i.e.,

$$\frac{\eta_{tr.}}{\eta_{TBL}} \simeq 4.13 \times 10^{-2} \left(\frac{Re_{x_1}}{Re_{x_o}}\right)^{1/5} \frac{Re_{\Delta x}}{y_c^+} \qquad . \qquad (29)$$

Typically, $Re_{\Delta x} \simeq 5 \times 10^5$, a conservative estimate for y_c^+ would be about 30, and the ratio of length Reynolds numbers to the 1/5 power is of order one. Therefore, equation (29) suggests that the laminar-to-turbulent transition zone generates noise more efficiently than does a fully-developed turbulent boundary layer, i.e. the transition zone radiation is approximately a thousand times more efficient.

III. CONCLUSIONS

In this note, we have derived an expression for the acoustic efficiency of boundary-layer transition based on an analysis by Lauchle [1], and a corresponding expression for the efficiency of fully-developed turbulent boundary layer flow based on an analysis by Tam [6]. We have compared these two efficiencies and found that the noise generated by boundary-layer transition

is considerably more efficient than that noise generated by a fully-developed turbulent boundary layer. For typical values of the Reynolds numbers upon which this comparison depends, *transition zone radiation* is shown to be about three orders of magnitude more efficient.

IV. <u>REFERENCES</u>

1. Lauchle, G. C., "On the Radiated Noise due to Boundary-Layer Transition," ARL TM 78-204, 28 July, 1978.

2. Farabee, T. M., Casarella, M. J., and DeMetz, F. C., "Source Distribution of Turbulent Bursts During Natural Transition," David W. Taylor Naval Ship Research and Development Center Report SAD-89E-1942, August 1974.

3. Schlichting, H., <u>Boundary Layer Theory</u>, 6th ed., McGraw-Hill Book Co., New York, 1968, page 598.

4. Chen, K. K. and Thyson, N. A., "Extension of Emmons' Spot Theory to Flows on Blunt Bodies," AIAA J., Vol. 9, pp. 821-825, 1971.

5. Tennekes, H. and Lumley, J. L., <u>A First Course in Turbulence</u>, The MIT Press, Cambridge, 1972, Chapter 5.

6. Tam, C. K. W., "Intensity, Spectrum, and Directivity of Turbulent Boundary Layer Noise," J. Acoust. Soc. Am., Vol. 57, pp. 25-34, 1975.

7. Landahl, M. T., "Wave Mechanics of Boundary Layer Turbulence and Noise," J. Acoust. Soc. Am., Vol. 57, pp. 824-831, 1975.

DISTRIBUTION LIST FOR UNCLASSIFIED TM 78-285 by G. C. Lauchle, dated November 7, 1978.

Commander
Naval Sea Systems Command
Department of the Navy
Washington, DC 20362
Attn: Library
Code NSEA-09G32
(Copies No. 1 and 2)

Naval Sea Systems Command
Attn: C. G. McGuigan
Code NSEA-03133
(Copy No. 3)

Naval Sea Systems Command
Attn: L. Benen
Code NSEA-0322
(Copy No. 4)

Naval Sea Systems Command
Attn: E. J. McKinney
Code NSEA-0342
(Copy No. 5)

Naval Sea Systems Command
Attn: E. G. Liszka
Code NSEA-0342
(Copy No. 6)

Naval Sea Systems Command
Attn: G. Sorkin
Code NSEA-035
(Copy No. 7)

Naval Sea Systems Command
Attn: T. E. Peirce
Code NSEA-0351
(Copy No. 8)

Naval Sea Systems Command
Attn: J. G. Juergens
Code NSEA-037
(Copy No. 9)

Naval Sea Systems Command
Attn: H. C. Claybourne
Code NSEA-0371
(Copy No. 10)

Naval Sea Systems Command
Attn: A. R. Paladino
Code NSEA-0372
(Copy No. 11)

Naval Sea Systems Command
Attn: D. Creed
Code NSEA-03132A
(Copy No. 12)

Commander
Naval Ship Engineering Center
Department of the Navy
Washington, DC 20360
Attn: W. L. Louis
Code NSEC-6136B
(Copy No. 13)

Naval Ship Engineering Center
Attn: F. Welling
Code NSEC-6144
(Copy No. 14)

Commanding Officer
Naval Underwater Systems Center
Newport, RI 02840
Attn: C. N. Pryor
Code 01
(Copy No. 15)

Naval Underwater Systems Center
Attn: D. Goodrich
Code 36315
(Copy No. 16)

Naval Underwater Systems Center
Attn: R. J. Kittredge
Code 36313
(Copy No. 17)

Naval Underwater Systems Center
Attn: J. Miguel
Code 36315
(Copy No. 18)

Naval Underwater Systems Center
Attn: B. J. Myers
Code 36311
(Copy No. 19)

Naval Underwater Systems Center
Attn: R. Nadolink
Code 36315
(Copy No. 20)

Naval Underwater Systems Center
Attn: D. A. Quadrini
Code 36314
(Copy No. 21)

DISTRIBUTION LIST FOR UNCLASSIFIED TM 78-285 by G. C. Lauchle, dated November 7, 1978.

Naval Underwater Systems Center
Attn: E. J. Sullivan
Code 36311
(Copy No. 22)

Naval Underwater Systems Center
Attn: R. Trainor
Code 36314
(Copy No. 23)

Naval Underwater Systems Center
Attn: F. White
Code 36301
(Copy No. 24)

Naval Underwater Systems Center
Attn: Library
Code 54
(Copy No. 25)

Commanding Officer
Naval Ocean Systems Center
San Diego, CA 92152
Attn: J. W. Hoyt
Code 2501
(Copy No. 26)

Naval Ocean Systems Center
Attn: A. G. Fabula
Code 5311
(Copy No. 27)

Naval Ocean Systems Center
Attn: M. M. Reischman
Code 2542
(Copy No. 28)

Naval Ocean Systems Center
Attn: G. L. Donohue
Code 2542
(Copy No. 29)

Commanding Officer and Director
David W. Taylor Naval Ship R&D Center
Department of the Navy
Bethesda, MD 20084
Attn: S. F. Crump
Code 1505
(Copy No. 30)

David W. Taylor Naval Ship R&D Center
Attn: W. B. Morgan
Code 154
(Copy No. 31)

David W. Taylor Naval Ship R&D Center
Attn: R. Cumming
Code 1544
(Copy No. 32)

David W. Taylor Naval Ship R&D Center
Attn: J. McCarthy
Code 1552
(Copy No. 33)

David W. Taylor Naval Ship R&D Center
Attn: T. Brockett
Code 1544
(Copy No. 34)

David W. Taylor Naval Ship R&D Center
Attn: Y. T. Shen
Code 1524
(Copy No. 35)

David W. Taylor Naval Ship R&D Center
Attn: M. Sevik
Code 19
(Copy No. 36)

David W. Taylor Naval Ship R&D Center
Attn: W. K. Blake
Code 1942
(Copy No. 37)

David W. Taylor Naval Ship R&D Center
Attn: T. M. Farabee
Code 1942
(Copy No. 38)

David W. Taylor Naval Ship R&D Center
Attn: F. C. DeMetz
Code 1942
(Copy No. 39)

David W. Taylor Naval Ship R&D Center
Attn: M. J. Casarella
Code 1942
(Copy No. 40)

DISTRIBUTION LIST FOR UNCLASSIFIED TM 78-285 by G. C. Lauchle, dated November 7, 1978.

Commanding Officer and Director
David W. Taylor Naval Ship R&D Center
Department of the Navy
Annapolis Laboratory
Annapolis, MD 21402
Attn: J. G. Stricker
Code 2721
(Copy No. 41)

Commander
Naval Surface Weapon Center
Silver Spring, MD 20910
Attn: G. C. Gaunaurd
Code R-31
(Copy No. 42)

Naval Surface Weapon Center
Attn: Library
(Copy No. 43)

Office of Naval Research
Department of the Navy
800 N. Quincy Street
Arlington, VA 22217
Attn: H. Fitzpatrick
Code 438
(Copy No. 44)

Office of Naval Research
Attn: R. Cooper
Code 438
(Copy No. 45)

Naval Research Laboratory
Washington, DC 20390
Attn: R. J. Hansen
(Copy No. 46)

Defense Documentation Center
5010 Duke Street
Cameron Station
Alexandria, VA 22314
(Copies No. 47 to and including 58)

National Bureau of Standards
Aerodynamics Section
Washington, DC 20234
Attn: P. S. Klebanoff
(Copy No. 59)

Rand Corporation
1700 Main Street
Santa Monica, CA 90406
Attn: R. King
(Copy No. 60)

Rand Corporation
Attn: C. Gazley
(Copy No. 61)

Jet Propulsion Laboratory
Pasadena, CA 01109
Attn: L. Mack
(Copy No. 62)

Hersh Acoustical Engineering
9545 Gozycroft Avenue
Chatsworth, CA 91311
Attn: A. Hersh
(Coph No. 63)

Dynamics Technology, Inc.
3838 Carson Street, Suite 110
Torrance, CA 90503
Attn: W. Haigh
(Copy No. 64)

Dynamics Technology, Inc.
Attn: D. Ko
(Copy No. 65)

Bolt Beranek and Newman
50 Moulton Street
Cambridge, MA 20136
Attn: N. Brown
(Copy No. 66)

Bolt Beranek and Newman
Attn: D. Chase
(Copy No. 67)

Bolt Beranek and Newman
Attn: K. L. Chandiramani
(Copy No. 68)

Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, MA 02139
Attn: Prof. Patrick Leehey
Dept. of Ocean Engineering
Room 5-222
(Copy No. 69)

DISTRIBUTION LIST FOR UNCLASSIFIED TM 78-285 by G. C. Lauchle, dated November 7, 1978.

Dr. J. L. Lumley
Sibley School of Mechanical and
Aeronautical Engineering
Upson Hall
Cornell University
Ithaca, NY 14850
(Copy No. 70)

Dr. D. G. Crighton
University of Leeds
Department of Applied Mathematical Studies
Leeds LS29JT
England
(Copy No. 71)

Applied Research Laboratory
The Pennsylvania State University
Post Office Box 30
State College, PA 16801
Attn: B. R. Parkin
(Copy No. 72)

Applied Research Laboratory
Attn: E. J. Skudrzyk
(Copy No. 73)

Applied Research Laboratory
Attn: G. H. Hoffman
(Copy No. 74)

Applied Research Laboratory
Attn: F. H. Fenlon
(Copy No. 75)

Applied Research Laboratory
Attn: G. C. Lauchle
(Copy No. 76)

Applied Research Laboratory
Garfield Thomas Water Tunnel File
(Copy No. 77)